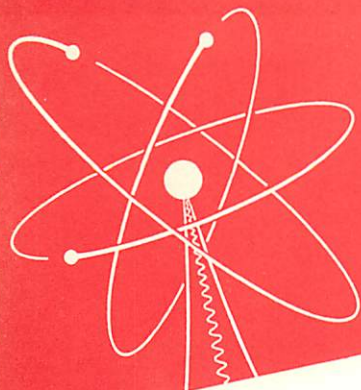




TV PRINCIPLES

Lesson T2C-1A



DeVRY Technical Institute

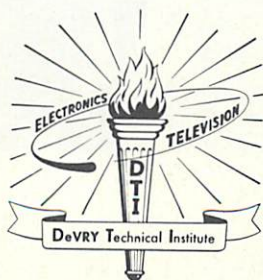
4141 W. Belmont Ave., Chicago 41, Illinois

Formerly DeFOREST'S TRAINING, INC.

TELEVISION PRINCIPLES

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A complete mobile television studio and microwave relay transmitter for televising sports, parades, and other news events to the main studio.

Courtesy Allen B. DuMont Laboratories Inc.

TELEVISION PRINCIPLES

Contents

	PAGE
Photo Electric Effect	4
The Television Camera Tube	5
Electric Potential Image	6
Basic Scanning Action	7
Camera Tube Scanning Beam	9
The Picture Signal	9
Picture Repetition Rate	11
Picture Quality	11
The Raster	12
Vertical Resolution	12
Vision Acuity	17
Normal Viewing Distance	20
Horizontal Elements and Frequency	20
Horizontal Resolution	22
Square Wave Elements	22
Total Picture Elements and Frequency	24

The world is moved not only by the mighty shoves
of the heroes, but also by the aggregate of the tiny
pushes of each honest worker.

—Frank C. Ross

TELEVISION PRINCIPLES

Hundreds of Television Stations today are providing top-rate entertainment, educational programs, and on-the-spot news in the living rooms of homes of millions of people. The Television Receiver has given a new lease on life to countless thousands of aged and shut-ins in homes and hospitals as the twist of a knob now unveils the majesty and color of the outside world.

The growth of television is affecting more and more the everyday life of everyone, and its future applications are seemingly limitless. Industry continues to turn to television for the solution of many of its problems in the application of remote control, and watching or monitoring meters and equipment. There is an increasing need for "television" in its provision for "seeing at a distance."

Various forest-ranger headquarters are equipping isolated towers with rotating television cameras from which a continuous picture of the condition of the surrounding territory is relayed by a microwave system back to a television receiver at ranger headquarters. The armed forces apply television in remote control of various units such as airplanes and guided missiles. The railroad industry continues to

make more use of television in monitoring track conditions and yard traffic. Some ships use television to give a clear view of every portion of the ship from the bridge while docking.

Along with this remarkable growth of television comes a rising demand for more qualified television technicians to maintain all of the electronic equipment required in the television field.

As has been mentioned in a previous lesson, this new world of television is the result of the discovery and development of light sensitive and light emitting materials.

PHOTO ELECTRIC EFFECT

After the discovery in 1873 that light affected the electric properties of selenium, the theory on the photoelectric effect began to advance. In 1887, Hertz discovered that he could make a spark jump more easily between two terminals at a given potential difference by applying ultraviolet light energy to the negative terminal. By early 1900, various other discoveries and studies proved that the photoelectric effect was directly proportional to the light illumination, and that some materials responded much differently than others. In fact it was soon established that light energy on

the surface of these materials actually released from the material many invisible electric particles which were soon called electrons.

In 1905, Einstein announced a theory of **photoelectric effect** which was that a light ray is collected into minute bundles called quanta. As these energy bundles penetrate a solid surface they cause some electrons in the atomic make-up of the material to become so activated that they fly free from the surface in a process of emission. Current then results in an electrically closed circuit when a positive electrode is placed near this emitting surface; when light is removed, current ceases.

In these intervening years it was found that alkali metals such as: Cesium, Rubidium, Potassium, Sodium, and Lithium were most affected by light energy; and of these CESIUM was found to be the most sensitive. The comparison in Figure 1 shows that the single electron in the outer shell of the cesium atom is farther away from the positive nucleus than in the other alkali metals indicated. Thus the cesium electron is knocked off or freed more easily by the bundles of light energy.

All of these important findings provided the way for the development of the photovoltaic cell now embodied in the light meter used by photographers, the photoelec-

tric cell used in many automatic devices, and finally the present-day photosensitive television camera tube.

THE TELEVISION CAMERA TUBE

The development of the television camera tube started in the early 1900's and followed along in the footsteps of the cathode-ray tube which had already been put to use several years earlier.



A television lookout tower for forest-fire detection. The visual information here is relayed by a microwave system to forest-ranger headquarters.

Courtesy Raytheon Manufacturing Co.

Included in the outgrowth of the camera tube action, appeared the **Image Dissector**, the **Iconoscope**, the **Image Orthicon**, and the **Vidicon**. The Image Orthicon and

the Vidicon which are used today have several thousand times the sensitivity of the Iconoscope.

Basically, a part of the television camera tube can be compared with the Human Eye. As shown by the sketch of Figure 2, in the human eye the light from the scene is focused by the lens upon the inner light sensitive coating on the rear wall. This light sensitive coating, called the retina, is composed of about 18,000,000 elements each of which reacts to light like a tiny photo sensitive cell. Each element is connected to the brain by an individual fibre of the optic nerve and is capable of acting independently of the others. Thus, each of these tiny light sensitive elements (rods or cones) can transmit to the brain information regarding the intensity and the position of the particular ray of light striking it. This information, simultaneously reaching the brain from all of the elements, forms instantly a mental image of the object viewed.

Figure 3 shows a partial drawing of the IMAGE ORTHICON camera tube. The picture is focused through the exterior lens in front of the tube onto the tube's "retina" which is a rectangular area about one inch high and one and one-fourth inches wide called the **photocathode**. The photocathode is actually a glass plate that is

coated on the back side with silver-cesium. This photosensitive plate emits electrons proportional to the light at each point. Thus the original picture is converted to a proportional electron emission from the back side of the photocathode surface as an invisible electron image of the exact detail and shading as the visible picture. In the human eye, this picture conversion is the function of the individual nerve fibres in the retina.

Electric Potential Image

This simultaneous emission representing the area and detail of the picture is accelerated and focused on to a second plate called the **target**. The target is actually a small plate of low-resistivity glass about .0002 of an inch in thickness. Here the **electron image** is intensified. By secondary emission, the electron image knocks off several electrons from the target for each electron coming from the photo cathode. Since there is now an electron deficiency, this leaves the target plate positively charged to the exact detail and shading of the original picture.

Immediately in front of the target facing the photo-cathode is a very fine mesh screen made of gold whose purpose is to collect the secondary electrons from the target. The original electron im-

age has enough acceleration to go through the gold screen and strike the target. Because the target is so thin, the electric charges representing each detail of the picture conduct straight through to the back side facing the electron gun. This final result on the target is referred to as an **electric-potential image**.

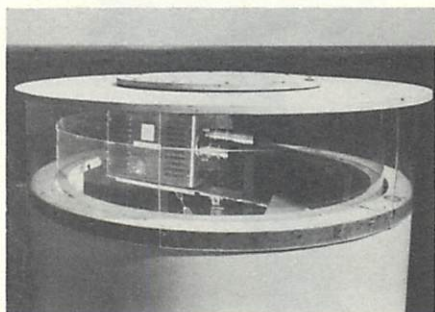
A simultaneous television transmission of this image such as is performed by the human eye is impossible since it would require a vast number of transmitters to handle all image units at the same instant. Therefore it is necessary to send each unit of the electric-potential image one at a time in rapid succession.

BASIC SCANNING ACTION

This basic idea is illustrated in the action diagrams of Figure 4. The surfaces portrayed are divided into squares to mark off the electric-potential areas representing charges proportional to the original light and detail of the picture in the camera tube. Diagrams 4A, 4C, 4E, and 4G represent the electric-potential image in the television camera at the transmitter.

Some type of selector which at any given instant can cover the area of only one square starts moving or **scanning** from the upper left-hand corner of Figure 4A

in a systematic way to hit every square area. As the selector responding to electric charges comes in contact with each potential area, it transmits the intensity of each unit area, called an **element**, to some type of reproducer which covers the same basic area. The surfaces in Figures 4B, 4D, 4F, and 4H represent the **screen** of a television picture tube. This reproducer again converts the electric pulse information into the visible picture.



A television camera inside a forest-fire lookout tower shown in the previous photo. The rotating camera gives a continuous picture of the surrounding territory.

Courtesy Raytheon Manufacturing Co.

The scanning sequence is as follows: The selector at the upper left unit or element of the camera in Figure 4A transmits a signal which causes the reproducer in Figure 4B to generate a bright unit or element at the upper left area of its screen.

The selector and reproducer must always be in the same position and move at the same relative speed to the right, and when

the second elemental area is reached, the selector transmits the information that this element is white also. This is shown by

third element of the third line, the selector transmits the fact that this area is shaded, and the reproducer correspondingly produces a shaded spot at this point on the receiver screen. The same information is transmitted when the selector and reproducer are at their respective fourth and fifth elements of the third lines, as shown in Figures 4E and 4F.

The action continues, element by element and line by line, until the entire area for both screens has been covered. Conditions at the eighth element of the tenth line, with the "picture" almost completed, are shown in Figures 4G and 4H.

When the selector and reproducer reach the bottom right-hand corner in a television system, they quickly return to the upper left-hand corner to start the entire procedure again.

This described method of scanning to obtain the picture elements is the same method used to read a printed page, such as this one. The eye begins at the upper left-hand corner, travels along the first line of words until it reaches the right-hand edge, then suddenly reverses its direction of movement and returns quickly to the left edge and the second line where it again begins its uniform left to right scanning action.



An iconoscope camera tube. The electron gun, at an angle, scans the rectangular photo-sensitive plate from the same side on which the pictures are focused.

Courtesy Radio Corporation of America

Figures 4C and 4D. Movement continues along the top line of elements. After a quick retrace, when the selector and reproducer are otherwise turned off, movement continues from left to right along the second line, etc. At the

Using this method of scanning an entire picture can be broken up element by element, sent in rapid succession by only one transmitter, and re-assembled in proper order or sequence by the reproducer in a television receiver. The final reproduced picture then is actually the result of varying dots of intensity systematically re-assembled. For example, a picture made up of a dot structure similar to this can be seen when examining very closely a photograph printed in a newspaper or this lesson.

CAMERA TUBE SCANNING BEAM

The selector in the camera tube such as the Image Orthicon is the cathode-ray beam which removes the electric-potential image element by element for proper transmission. It might be said here that the area or element information that the cathode ray spot covers as a selector contains a number of tiny photo-image charges whose combined average effect is registered by this selector beam spot. The small size of the cathode ray spot still provides good picture detail in reproduction.

In Figure 5 is a drawing of the Image Orthicon showing the path of the cathode-ray beam relative to the target of the tube. We mentioned before that an electric-po-

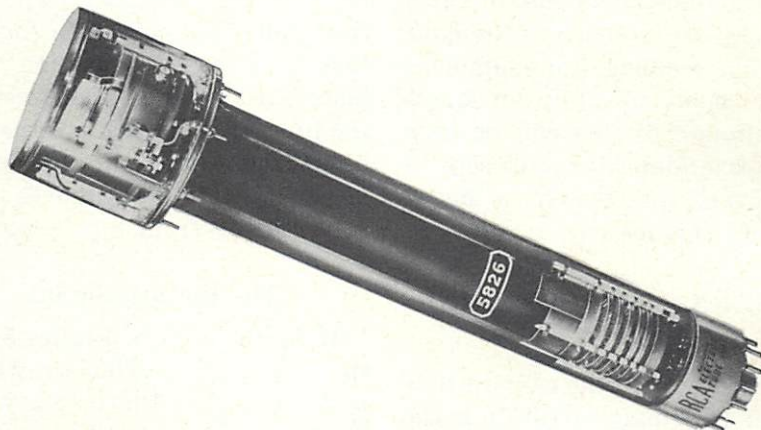
tential image is obtained on the target by a process involving secondary emission. The beam spot from the **electron gun** is caused to scan this electric image in the same manner described previously in Figure 2. The scanning movement of the beam is produced by the action of horizontal and vertical deflection coils in a unit referred to as a deflection **yoke** placed around the outside neck of the tube. It is pointed out that the beam thus goes through many horizontal lines as it moves slowly vertically from top to bottom.

The Picture Signal

It can be seen in Figure 5 that the very slender cathode-ray beam is forced up to the target where it turns around and goes back into the neck of the camera tube. Thus the beam boomerangs. The voltages are such in the tube that they first accelerate, then decelerate the beam's speed as it approaches the target. The electron beam then barely "nuzzles" the target as it turns around and heads back to the higher potentials in the base of the tube. As the beam comes close to the target, electrons are taken from it by the positive potentials of the electric image. In reality then, the return beam of electrons to a positive element in the base of the tube is modulated by the robbing action of the target. Thus each picture element one after the

other will be individually registered as variations in the return beam. These picture signal variations are coupled from the collector element of the camera tube

Orthicon; since, for every electron in the beam entering the multiplier, the secondary emission process can cause approximately 1000 electrons to leave and ap-



The image orthicon camera tube. Observe the electron-multiplier dynodes near the base of the tube.

Courtesy Radio Corporation of America

to a picture or video amplifier tube by the usual methods.

Incidentally, the element referred to in the camera tube to which the beam returns can be noticed in Figure 5 where it is called an **electron-multiplier**. As shown in Figure 6, it is made up of a progression of angled metal sections which are secondary emissive in quality. This increases the signal output of the Image

pear in the signal output load. In Figure 6 this multiplying action is suggested by the fact that two secondary electrons are emitted from plate No. 1 for every electron striking it. Since each plate doubles the number of electrons, there are 8 electrons leaving plate No. 3 for every one striking No. 1. In actual practice 4 or 5 secondary electrons are emitted for each electron striking the plate.

In the television receiver this picture signal is applied in the control grid-to-cathode circuit of the cathode-ray tube where it varies the intensity of the beam directly proportional to the original picture elements. The varying cathode-ray beam is caused to scan the screen of the picture tube by a horizontal and vertical deflection system which is synchronized by pulses from the transmitter putting this beam in identical sequence and position as the beam in the camera tube. Thus its changing intensity, element by element, reconstructs the original picture on the fluorescent face of the picture tube.

PICTURE REPETITION RATE

Since the persistence of vision of the human eye is $1/16$ of a second at most, the entire picture must be reconstructed in $1/16$ of a second or less in order that the impression of the first or upper left-hand corner element does not die away before the last or lower right-hand corner element is produced on the receiver screen.

Although the eye "sees" a complete image at this rate, a disturbing flicker is noticeable and, to overcome this effect, a higher picture reconstruction speed is used. A similar condition is found in motion pictures since the film actually consists of a great many

still pictures, each differing slightly from those immediately preceding and following it. Here it has been found that a picture-repetition rate faster than 15 per second is sufficient to produce the illusion of motion without excessive jerkiness, and to satisfy the **persistence of vision** of the eye, the individual pictures may be projected on the screen at a rate of 16 per second.

However, for sound pictures, the projection rate has been increased to 24 pictures or **frames** per second to reduce the disturbing flicker. In modern television the entire image is completely scanned in about $1/30$ of a second to provide a picture. Hence, television has a "frame" frequency of 30 pictures per second.

PICTURE QUALITY

The number of scanning lines required to faithfully reproduce an image has been determined in a practical manner by Engstrom. He projected motion pictures through a multiple-lens system of embossed celluloid in such a way that the pictures appeared to have a line structure similar to that of television images. By this method he found that at least 400 to 500 lines are required to give the same apparent picture quality as the original film projected directly.

The Raster

The present television system breaks up the picture into approximately 525 lines some of which at the top and bottom of the picture are blanked out and so are not active in the picture. These lines then scan the entire picture once every $1/30$ of a second to make possible the frame frequency of 30 pictures per second. The total rectangular area illuminated by the scanning pattern of 525 lines is referred to as the **raster**.

In order to understand what factors determine the quality of the reproduced picture in this system, we shall first consider the vertical breakup of the picture into elements by the scanning lines.

Vertical Resolution

The conditions which occur between the relative size and position of the vertical picture details with respect to the scanning lines are illustrated by Figure 7. The surface areas 7A, 7C, 7E and 7G on the left represent portions of electric-potential images which contain small vertical details of a picture to be televised. The areas also show the relative vertical position of these elements to the electron-beam scanning-line pattern in the camera tube. The surface areas of 7B, 7D, 7F, and 7H on the right represent the results in corresponding picture informa-

tion as it is registered by the camera tube cathode-ray beam itself and finally reproduced by the receiver picture tube cathode-ray beam.

Only eleven scanning lines are shown in a magnified view, since all the effects in the following discussion concern the reproduction of tiny vertical elements of a picture in any given space only $3/10$ of an inch high on the face of a 21 inch picture tube. This includes only about 2% of the height of an entire picture when using 485 active-lines.

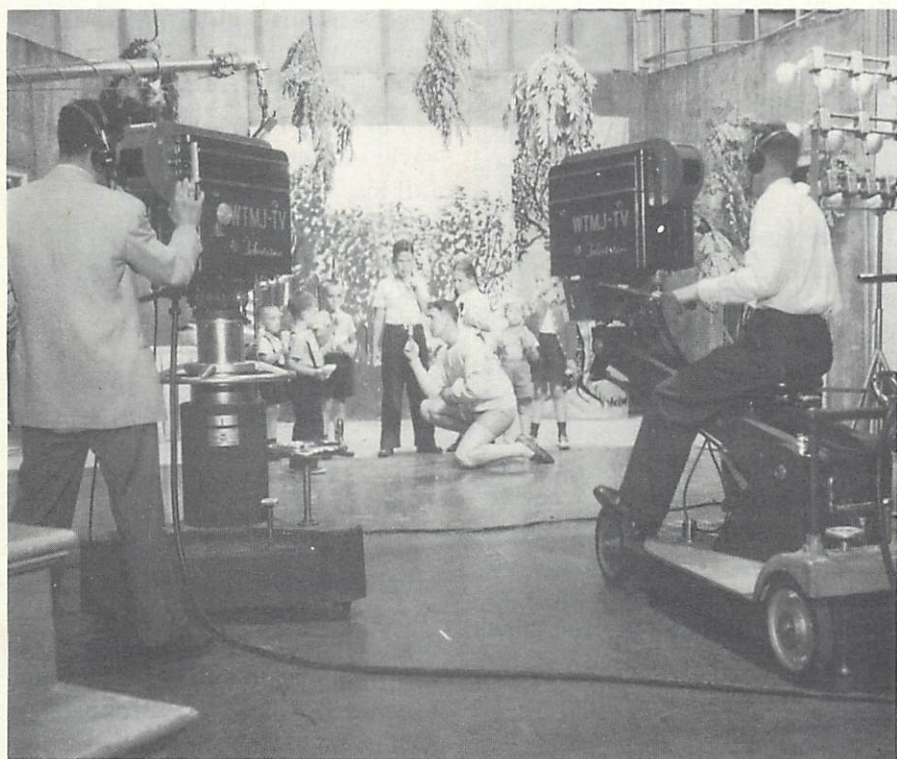
The two dark and two white areas, located between the two vertical lines near the center of Figure 7A, represent small vertical details, or elements, of the scene to be televised. As the spot moves from left to right across scanning line 1, during the time it passes over the dark detail, the information registered by the camera beam and transmitted to the receiver causes the scanning spot to be reduced in brilliance and reproduce a dark area on the picture tube screen. Therefore, in Figure 7B, the small dark area in the center of scanning line 1 corresponds to the area covered by the dark picture detail under scanning line 1 of the camera image in Figure 7A. This action is repeated as the spot moves across scanning lines 2 and 3.

For scanning lines 4, 5, and 6, the picture detail is white, and this registered beam information, transmitted to the receiver, causes its scanning beam spot to remain at maximum brilliance and produce a corresponding white area at the center of the screen.

So far, the image on the receiver screen corresponds exactly to

dark detail at the top and the white detail immediately below falls exactly on the boundary between the third and fourth scanning lines.

However, the division between this white detail and the lower dark detail falls in the middle of the seventh scanning line position, while the lower limit of this



A studio program being televised. These television cameras employ the image orthicon camera tube. Note the microphone boom at the upper left.

Courtesy WTMJ—TV Milwaukee

the scanned electric-potential image of the camera tube because the sharp division between the

dark detail falls in the middle of the tenth scanning line position. Under these conditions, areas a

and b in lines 7 and 10 of Figure 7A, contain exactly half the light of a completely white area.

Thus in this scanning line region, one-half of the tiny image charge covered by the small vertical dimension of the beam spot will have a high positive potential relative to a white condition, while that area under the other half of the spot element will have no positive image potential because of the black condition. Since the beam spot is one unit and cannot be split, the total number of electrons taken from the beam at this instant will be an average equal to the positive potential under that half of the beam spot which covers the area relative to white. The total number of electrons in the whole beam then will be equal to a condition midway between black and white. This is the modulating signal at the moment which finally causes the receiver picture tube beam spot to register an intensity area on the picture tube screen that is an intermediate brilliance between black and white, or gray. This result is shown in line 7 and line 10 of Figure 7B.

Because the vertical edges of the picture details do not coincide with the edges of the scanning lines there is a blurred or indistinct boundary between the vertical elements of the reproduced image on the receiver screen as

compared to the original elements. That is, the white and dark areas appear to overlap to an extent equal to the width of a scanning line.

The seriousness of this effect depends upon the size of the vertical picture details; the overlap region will always be equal to the width of one scanning line whether the vertical picture "detail" covers several hundred scanning lines, or only two or three as shown in Figure 1A.

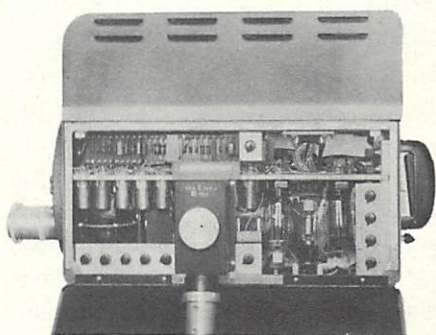
For larger vertical areas which cover many scanning lines, a detail loss equal to the width of one line is not very evident, but if the vertical elements are tiny, as in Figures 7A and 7B, then the detail loss is noticeable at close viewing range giving that part of the image a fuzzy or an out-of-focus appearance. In practice, some of the vertical edges of the tiny picture elements coincide with the scanning lines and no fuzzy appearance occurs, while others overlap the scanning lines for a less accurate reproduction. Many elements take intermediate positions, that is, they overlap, but not to the extent of covering half a scanning line. Therefore, the condition of this minute detail change varies all the way from nearly white to black, depending upon whether a white or black vertical picture element covers most of the overlapped scanning line.

Thus, since only the edges of minute picture elements can cause this detail loss, images containing mostly large objects are less likely to have a fuzzy or out-of-focus appearance than those made up of many small objects with a correspondingly larger number of edges for a given number of lines.

The ideal conditions for transmission of maximum picture detail in the vertical direction are illustrated in Figure 7C and 7D where the vertical dimensions of picture detail are equal to the width of the scanning lines, and in addition, the elements are spaced and located so that they fall exactly on the scanning lines with no overlap. No gray areas are produced on the receiver screen, where black or white elements should appear, and with the black and white picture details immediately adjacent to each other, maximum image contrast is obtained. On the receiver screen, the reproduced image contains the same number of vertical elements as the object at the transmitter, which in this case is equal to the number of scanning lines. THEREFORE, IF 485 SCANNING LINES ARE USED, THEN 485 VERTICAL ELEMENTS IN THIS CASE CAN BE REPRODUCED ON THE RECEIVER SCREEN.

The extreme opposite of this condition is shown in Figure 7E, where again, the picture details

are equal in height to the height of the scanning lines. However, instead of falling exactly on the scanning lines, as in Figure 7C, the details straddle the lines. Therefore, as described for the seventh and tenth lines in Figures 7A and 7B, gray areas are produced on all the lines of the



An open view of a television camera. The shielded miniature tubes provide the amplification for the picture signal. The other larger tubes at the right are used for beam deflection and high voltage.

Courtesy Allen B. DuMont Laboratories Inc.

receiver image to form the pattern of Figure 7F. As neither black nor white areas are created, the reproduced image in this $3/10$ of an inch space mentioned before is simply one uniformly shaded vertical line or element instead of 11 individual elements.

Figures 7C and 7D represent the best condition, while the poorest case is represented in Figures 7E and 7F with the same number of elements.

In actual practice, some of the picture elements will fall on the scanning lines as in Figure 7C, some will straddle the scanning lines as in Figure 7E, but most of them will occupy some intermediate position so that, although every reproduced line will not be completely white or black for a small element as in Figure 7D, neither will they all be the same shade of gray, as in Figure 7F.

Therefore, in the parts of the scene where the size of the picture elements is about equal to the thickness of the scanning lines, the average number of vertical picture elements reproduced on the receiver screen will be somewhat less than the number of scanning lines.

It has been found that the average number of reproduced vertical elements due to this spot overlapping is equal to about 80% of the total number of active scanning lines. Thus, in a system with 485 active scanning lines, the average number of reproduced tiny vertical elements is 80% of 485 or 388.

Another possible set of conditions is represented in Figure 7G where the height of the picture elements in the scanned pattern is only one-third the width of the scanning lines. At the top, the black and white elements are evenly spaced and do not straddle the boundaries between lines, but,

at the bottom, the black elements, still equal to one-third the scanning line width, are randomly spaced so that the white elements vary in height.

As one-third of scanning line 1 is occupied by a black element and two-thirds by a white element, the transmitted information causes a light gray, closer to white than to black, area on the corresponding scanning line at the receiver. The shading covers the entire width of the line and the respective white and black picture elements are combined into one light gray element with a height equal to the width of the scanning line.

At the camera tube, the beam in scanning line 2 covers one white and two black picture elements, which combine to give a dark gray element in the corresponding area on the receiver screen. The scanning device responds only to the total light in the areas covered by the scanning spot at any instant, therefore, again, the individual extremely minute picture details are lost, being merged into one element which is dark gray in shade and equal in height to the width of the receiver scanning line.

On scanning line 3, the action is the same as on line 1 to reproduce a light gray element and, like line 2, line 4 produces a dark gray element on the receiver screen. The height of each repro-

duced vertical element is equal to the total height of three elements in the original scene. Thus, for the top four scanning lines, the twelve original picture elements of Figure 7G are reduced to four in the reproduced image of Figure 7H. Although varying in shade, none of the reproduced elements are totally black or totally white like the elements scanned by the camera.

Summarizing this action: the maximum number of vertical elements which can be transmitted is limited by the total number of scanning lines, even though the original scene may contain more elements than there are lines in the scanning pattern. Scanned by the lines of Figure 7G, the reproduced image of Figure 7H is only an approximation of the original object, being darker in the regions where the dark picture elements are concentrated and brighter in the regions where the white picture elements are concentrated.

The lower part of Figure 7G more closely resembles the conditions in an actual scene, and checking here, scanning lines 5 and 6 each cover the same amount of light as lines 1 and 3, consequently, gray areas of the same intensity are produced on the receiver screen. The white picture elements in scanning line 7 are very narrow, and therefore, a very

dark, almost black element is produced on the picture tube screen. Continuing on down in Figure 7G, similar actions occur for all except line 10, which crosses an all white region and produces a white element on the pattern of Figure 7H.

Although the details in the scanned scene of Figure 7G are not reproduced exactly, the image in the representative 3/10 of-an-inch height of Figure 7H corresponds to the original in a general way because it is darkest where the dark elements are concentrated and lightest where the light elements are concentrated. The scanning pattern of Figure 7G reduces the thirty original vertical elements in the space to eleven. In Figure 7H, ADJACENT LINES 5 AND 6 HAVE IDENTICAL SHADING AND APPEAR AS A SINGLE ELEMENT TO REDUCE THE TOTAL OF THE REPRODUCED IMAGE TO TEN VERTICAL ELEMENTS.

All of these conditions and effects dealing with the vertical picture elements sometimes are referred to as **vertical resolution**.

Vision Acuity

To the viewer of a normal television receiver, the condition just described in the reproduction of the tiny vertical picture elements is not noticeable from an average viewing distance. It takes into consideration a quality known as

the **acuity of vision** which involves the ability of the eye to distinguish details or elements of small dimension.

To illustrate this characteristic, Figure 8A consists of two heavy black horizontal lines separated by a thin white line, each of which can be considered as an element of a scene. At ordinary reading distance, the white line



This large-screen table-model receiver can be placed with little effort in any room. Notice the standard picture width-to-height ratio of 4:3.

Courtesy CBS—Columbia

can be seen, but by increasing the viewing distance between the lines and your eye, the white line becomes harder and harder to see until, at a distance of over ten or twelve feet, the separation between the two black lines is no longer visible and they apparently merge into one heavy line.

Therefore, at a given distance, there is a limit to the detail, or size of small images, that the human eye can distinguish.

In much the same manner the many scanning lines which make up the television picture lose their individuality and merge into the total picture at a certain viewing distance from the picture tube which is similar to how the artist's brush marks merge in a beautiful painting or the dots disappear on a picture printed in a magazine or book when viewed from a certain distance.

In relation to this, some interesting experiments can be performed by the reader on the diagrams of Figure 7, if space is available. It will be found that at a nominal distance of about 50 feet, Figures 7C and 7D merge into one vertical element such as in Figure 7F. Corresponding conditions of element-merging at various viewing distances also will occur for the other diagrams of Figure 7.

Recalling now that these diagrams are a magnified view of only about $\frac{3}{10}$ of an inch vertically of a 21 inch picture tube, a comparative viewing distance of approximately 11 feet from a 21 inch receiver would cause the eye to have the same acuity-of-vision result for the 11 lines in spite of the detail present. A merging of the tiny elements into one 11-line-

high element would cover only 2% of the height of a complete picture. Even though a receiver reproduces the original 11 small vertical elements, the eye will average them beyond a certain distance within the viewing range.

It has been found that there is a normal relationship between viewing distance and minimum visible object size for the average human eye. This relationship for seeing an object is shown in Figure 8B. Angle θ averages about $1/60$ of one degree or 1 minute ($1'$), h represents the size of the object or element and d represents the maximum viewing distance the eye can be from the object and still see it. As the diagram shows, when the viewing distance increases to d_1 , the required object size h_1 must also be larger in order to be distinguished. For some individuals, the acuity-of-vision angle may be down to $1/120$ of a degree or $1/2$ minute ($1/2'$) while in others it may be $2/60$ of a degree or 2 minutes ($2'$), etc.

In Figure 8C is a chart which shows the relationship of these three different angles of vision acuity mentioned. It compares the dimensions of viewing distance in feet to minimum detail, or h requirements, in hundredths of an inch.

It has been explained that, theoretically, the smallest picture de-

tails which can be reproduced are equal in height to the thickness of one scanning line. As an example, suppose that on the face of the twenty-one inch picture tube, the viewing area of 485 lines is 14 inches in height. The thickness of one line and therefore, the height of the smallest possible reproduced picture element is less than .03 inch. According to the $\theta = 1'$ curve of Figure 8C, the maximum distance at which a viewer with normal vision can be from the screen and still see the smallest elementary picture detail, is about 8 feet.

This holds true if the images are perfectly stationary and the scanning beam traces have uniform distribution of light across their thickness. In practice, neither of these conditions is completely true, therefore, the actual ability of the eye to distinguish picture elements is less than that indicated by the above example which represents the best possible case.

With movement occurring in the scene, the resolving power of the normal eye is such that the angle θ , produced by the smallest visible detail, approaches 2 minutes. This represents an intermediate condition, and in worse cases, the angle θ may be equal to as much as 5 minutes or more. According to curve $\theta = 2'$, Figure 8C, a picture detail which is

slightly less than .03 inch as assumed in the former example, must be viewed from a distance not greater than about 4 feet in order to be seen. However, 4 feet, or 48 inches, is only 3.4 times the 14 inch height of the picture.

Normal Viewing Distance

Experience with television and movie audiences has shown that watching the picture from a distance less than 4 or 5 times its height causes tiring of the viewer's eyes because at close range the eye must move excessively to cover the entire picture area. This movement of the eye is necessary since only the region at the center of the retina is capable of distinguishing details to the extent indicated in the graphs of Figure 8C. Therefore, in order to "see" details over the entire picture area, the eye muscles must be in action constantly so that all the regions of the picture area may affect this sensitive center portion of the retina.

Experience shows also that freedom from strain of eye muscles is more important than the ability to see tiny picture details, therefore, a viewing distance somewhat greater than that which allows maximum discernment of picture elements is desirable. On the other hand, if the viewing distance is too great, the picture oc-

cupies an extremely small field of view, and again considerable eye strain is produced.

Experiments with various television audiences has indicated that the optimum viewing distance therefore ranges from about 4 to 10 times the picture height.

HORIZONTAL ELEMENTS AND FREQUENCY

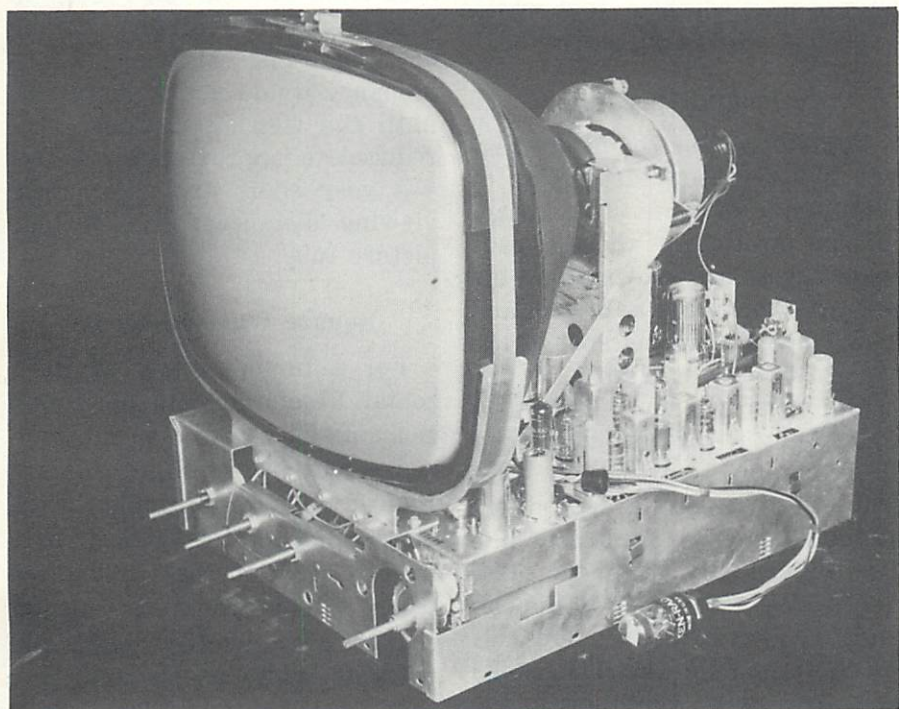
As the cathode-ray spot sweeps a line from left to right there are no symmetrical divisions or dividing points in the line itself to produce a basic elementary condition such as is encountered by the division between each line in a vertical direction. Thus an extremely large number of picture horizontal variations or horizontal elements could occur in each line depending upon the detail in the picture.

For example, if a suit coat with a fine tweed weave arrangement were televised in a close-up for an advertisement, you can imagine the large number of times the beam spot intensity would change in one horizontal scan as it responded to the picture detail representing a cross section of the varied threads used in the make-up of the coat. Of course, the appreciation for the finer points of detail that would be present would again depend upon the viewing distance and the "acuity

of vision" of the viewer's eye. As will be shown later, the actual limiting factor for the receiver's reproduction of these horizontal elements is the frequency response limit for the television system.

The term frequency in electronics takes into account a certain number of cycles per second. One cycle of a sine wave, for ex-

POSED OF TWO VARIATIONS OR TWO ELEMENTS, but not necessarily identical. Figure 9 shows one such line scanned and its signal voltage counterpart. Only three variations or elements are present for the entire line. First, a bright element will occur followed by a dark element for a short period and then another long-time-peri-



A typical television receiver chassis. The transformers and miniature tubes on the exposed side amplify the picture and sound signals.

Courtesy Allen B. DuMont Laboratories Inc.

ample, is composed of two alternations or variations. Basically then, ONE CYCLE OF INFORMATION OF A TELEVISION PICTURE IS COM-

posed of two variations or two elements to complete the line. These three elements compose $1\frac{1}{2}$ cycles of picture information in rectangular voltage

changes rather than sinusoidal. The result is a positive variation for white first, then a negative variation for black, followed by another positive variation for white.

When the size of the horizontal element approaches the size of the scanning spot, a condition similar to that described as element overlap for vertical resolution occurs, and, in part concerns that which is termed **horizontal resolution**.

Horizontal Resolution

To analyze this condition, Figure 10A represents a portion of three scanning lines. The instantaneous positions of the spot as it scans across are shown along the line at five points—a, b, c, d, and e. When the scanning spot of the camera tube is at point a on line 1, the element under the spot is white and the camera and receiver beams are such that the original white element is reproduced at the receiver at point a of line 1 of Figure 10B. When the scanning spot gets to point b, the elementary area covered is now half white and half dark; this results in an averaging condition in the camera and receiver tube beams.

The result in Figure 10B is a gray area reproduced on the receiver screen at point b of line 1. At point c the dark element now is completely covered by the scanning spot for a correspondingly

reproduced dark element at the receiver. Point d again averages out to a gray reproduction at the receiver while point e is again a completely reproduced white area. As can be seen, the original dark element in horizontal detail has been slightly distorted. Considering the fact that the spot diameter on a 21 inch picture tube can approach .02 of an inch, it can be seen from the chart in Figure 8C that even under perfect stationary conditions this element discrepancy would not be noticeable until the viewing distance were reduced to approximately 3 feet—a very short and impractical viewing distance for a 21 inch picture tube.

Square Wave Elements

For a further study of Horizontal Resolution and horizontal elements let us examine the various conditions in Figure 11. In Figure 11A, for example, if the black and white vertical bars were a part of the transmitted scene, there would be abrupt changes from white to black and black to white as the scanning beam moves across them. These sudden changes with uniform color in between would produce a square wave signal voltage like that drawn below the bars. Notice here, each pair of bars, one white and one black, produces one complete square wave cycle.

However, in the event that these original vertical bars were each equal to the width of one picture element, the beam spot averaging condition similar to Figure 10B, the frequency limit of the system, and the acuity of vision, would all play a part in producing the pattern shown in Figure 11B, which would be a series of sine wave intensity changes as borne out by the wave-form at the top of the pattern.

All radio and television circuits are composed of various combinations of resistance, inductance, and capacitance or their equivalents. In addition, the inductance or capacitance in a circuit can change or distort the signal wave-forms of all except sine wave signals. For this reason, signal circuit theory often is based on the action of fundamental and harmonic sine wave currents and voltages. In order to study the action of various types of wave-forms in these circuits, it is customary to consider these wave-forms as harmonic combinations of sine waves.

It is known that a SQUARE WAVE, such as that in Figure 11A IS EQUIVALENT TO A SINE WAVE OF THE SAME FUNDAMENTAL FREQUENCY AS THAT OF THE SQUARE WAVE, PLUS A LARGE NUMBER OF ODD HARMONICS. For example, a number of sine waves of 40 cps, 120 cps, 200 cps, 280 cps, 360

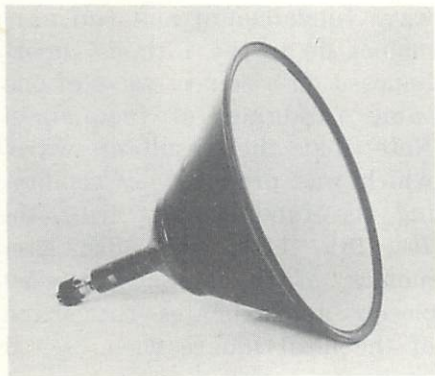
cps, etc., when added in proper phase and relative amplitudes, make up a square wave of 40 cps.

To illustrate this action in greater detail, in Figure 11C a wave-form containing the sine wave fundamental and odd harmonics up to the 13th, is superimposed on a square wave of the same fundamental frequency. Note that the resultant wave, which was produced by combining the fundamental, 3rd, 5th, 7th, 9th, 11th, and 13th harmonics, of the sine wave very closely approximates the shape of the ideal square wave.

In Figure 11D, a similar wave containing the odd harmonics up to the 21st is superimposed upon a square wave of the same fundamental frequency. This wave-form approximates the ideal square wave even more closely than that of Figure 11C.

However, it has been found that television circuits which pass frequencies up to and including the thirteenth harmonic of a given square wave picture signal, provide for good reproduction of this square wave that might represent sharp edges of contrasting objects in a picture. Thus, if the vertical bars of Figure 11A were of a practical dimension, say slightly less than $\frac{1}{2}$ inch width for each bar on a 21 inch picture tube, a square wave signal voltage with a fundamental frequency

of approximately 320,000 cycles per second would result. If the television circuits are to handle this square wave signal without distortion, and apply the same



A metal-coned round picture tube. The round edges would be masked off by the cabinet for the usual rectangular picture.

Courtesy General Electric Co.

wave-form into the grid circuit of the picture tube, they must have a frequency response out to approximately the 13th harmonic of the fundamental 320,000 cps so that the bars can be reproduced with sharp edges. This would require a frequency response of $13 \times 320,000$, or 4,160,000 cps or approximately 4.2 mcs. which is about the upper frequency limit of the television system.

TOTAL PICTURE ELEMENTS AND FREQUENCY

In order to more readily associate a complete television picture

with total elements and frequency, the diagram of Figure 12 assumes horizontal divisions, and is thus made up of square elements with equal horizontal and vertical spacing. Only 18 scanning lines are shown, and in this case, represents the possible maximum number of vertical elements transmitted. The television standard scanning pattern or raster is $4/3$ wider than it is high; thus in using square elements for the diagram of Figure 12, $4/3$ as many elements will appear in one horizontal line as compared to a vertical direction.

For this example, since there are 18 vertical elements, the number of horizontal elements is equal to $4/3 \times 18$, or 24. Thus the actual number of elements over this entire pattern is equal to 18 (vertical elements) $\times$ 24 (horizontal elements) or 432 total elements in one complete scanning sequence of the pattern. Since 30 patterns or pictures are completely scanned every second in the television system, there would be 432 (elements per picture) $\times$ 30 (pictures per second), or 12,960 elementary variations in the picture amplifier circuits each second.

As has been stated, every two variations or elements make up one cycle of picture information; therefore the fundamental frequency of the picture signal in-

formation in this example would be $12,960 \div 2$, or 6,480 cycles per second. Any circuits used in the amplification of this signal information would have to have the proper frequency response characteristic. If horizontal square wave changes were present in the pattern as might be indicated, the frequency response of the circuits would have to extend to approximately the 13th harmonic of 6,480 cycles or 84,240 cps. for a theoretical faithful reproduction.

Incidentally, because of spot overlap as mentioned previously, a final reproduced pattern by the cathode-ray beam would resolve only about 80% of the original vertical elements; this would be equal to 80% of 18, or $14\frac{1}{2}$. The average total of reproduced elements in the pattern would then be $14\frac{1}{2}$ (average vertical elements) $\times$ 24 (horizontal elements), or 348. It would be referred to as a reproduced 348-element picture.

A similar overall procedure can be followed in determining an approximate total element structure and frequency characteristic in the standard television system using 485 active scanning lines.

There would now be 485 original vertical picture elements and $485 \times 4/3$, or 647 assumed horizontal elements. Incidentally it would be impossible for the human eye to discern such tiny elements

within the average viewing distance range, and pictures in general have quite a few less horizontal variations or elements with a rough average around 300.

In the example for a symmetrical arrangement of element structure, the total number of original picture elements in one complete scanning sequence would be 485 (vertical elements) $\times$ 647 (horizontal elements) or 313,795 per picture. It has been found that a well reproduced television picture will contain from 100,000 to 200,000 elements. A 16 mm movie film has a structure equal to about 125,000 elements.

In the example, with 30 pictures per second, there would be $313,795 \times 30$, or 9,413,850 elements. This sets up a frequency of $9,413,850 \div 2$, or 4,706,925 cps., which is approximately 4.7 mcs. This frequency of element repetition would produce tiny variations beyond the ability of the human eye to discern at the normal viewing distance and falls outside the approximate 4.2 mcs. limit of the television system.

If a 4.2 mcs picture signal square wave were to be transmitted by the television system without distortion, it would require basic picture signal circuits with a frequency response extending out to about the 13th harmonic of 4.2 mcs., or 54.6 mcs. Since the system's upper limit is

approximately 4.2 mcs., the 4.2 mcs. square wave would be distorted by the circuits into a sine wave, and the actual sine waveform shown in Figure 11B would appear in the picture tube grid circuit to reproduce this pattern discussed previously. As has been mentioned, at such a high-frequency element rate, even a square-wave voltage signal would become the same average pattern as Figure 11B; nothing is lost to the eye insofar as the interpretation of the entire picture is concerned when the comparatively few existing, extremely tiny elements are in the 4 mcs. frequency region altered by ACUITY OF VISION, BEAM SPOT AVERAGING, and FREQUENCY RESPONSE.

Since the complete television system involves the transmission and reception of both picture and sound information for one station channel, proper standards and circuit arrangements must be followed in the transmitter and receiver to accommodate these basically different signals. Along with this, the scanning action in

the television system requires an additional complex pulse signal to synchronize all beam deflections. This signal keeps the camera and receiver beam spots in identical scanning positions, thus making picture reproduction possible.

A rigid standardization of these television signals becomes evident when we consider that all television stations must be received and their pictures reproduced by all makes of television receivers.

The makeup of an entire television program transmission includes picture information for controlling beam spot brightness, pulse information for controlling beam deflection, and audio information to excite the speaker for sound.

The following lesson will give a more complete account of these signals and the basic circuit arrangements used, along with various Federal Communications Commission Standards established for all television broadcasting.



IMPORTANT DEFINITIONS

ACUITY OF VISION—[uh KYOO: uh ti]—A limiting factor of the eye to see detail.

ELECTRIC POTENTIAL IMAGE—A voltage image of the original picture.

ELECTRON GUN—The elements of a cathode ray tube which produce and accelerate the electron beam.

ELECTRON IMAGE—The image formed by the photoemitted electrons and projected on the target of an image orthicon camera.

ELECTRON MULTIPLIER—The electrodes at the base of the image orthicon which are secondary emissive used to increase the picture signal output.

ELEMENT—A fundamental unit of light detail in the makeup of a picture (2 elements equal one cycle).

FRAME—[FRAY'm]—One complete picture.

HORIZONTAL RESOLUTION—[res uh LOO: sh'n]—The quality of detail of the horizontal elements of a picture.

ICONOSCOPE—[igh KAHN uh skohp]—A camera tube in which the optical image is focused directly on a light sensitive plate where an electric-potential image is produced and scanned.

IMAGE ORTHICON—[AWR thi kahn]—A camera tube in which an electric-potential image is indirectly formed on the target by a projected electron image. The target is scanned by low velocity electrons. The signal output is increased in amplitude by an electron multiplier.

MICROWAVE—A transmission system which uses extremely high carrier frequencies in the spectrum above 1000 mcs.

PERSISTENCE OF VISION—The ability of the eye to retain an image of an object after the object has been removed.

IMPORTANT DEFINITIONS—(Continued)

PHOTOCATHODE—[foh toh KATH ohd]—A surface that emits electrons when struck by light rays.

PHOTOELECTRIC EFFECT—The releasing of electrons by some materials when illuminated by light.

RASTER—[RAS ter]—The pattern of lines formed on the picture tube screen without the presence of a picture.

SCANNING—[SKAN ning]—The process of examining the picture elements in a definite sequence.

SCREEN—The inside surface coating of the glass face of a picture tube which becomes luminescent when struck by a beam of electrons.

SYNCHRONIZED—[Sing kruh nizd]—A condition where the cathode ray beam in the receiver picture tube is in step with the beam at the transmitter camera.

TARGET—The thin glass plate on which the electron image falls in an image orthicon camera tube.

VERTICAL RESOLUTION—The quality of detail of the vertical elements of a picture.

VIDICON—[VID i kahn]—A camera tube in which the optical image is focused on a photoconductive target. The electric image is formed by increased conductivity for the electron beam in the illuminated portions of the scene.

YOKE—[yohk]—A television component which fits around the neck of a cathode ray tube. It contains 2 pairs of coils which magnetically deflect the electron beam horizontally and vertically.

STUDENT NOTES

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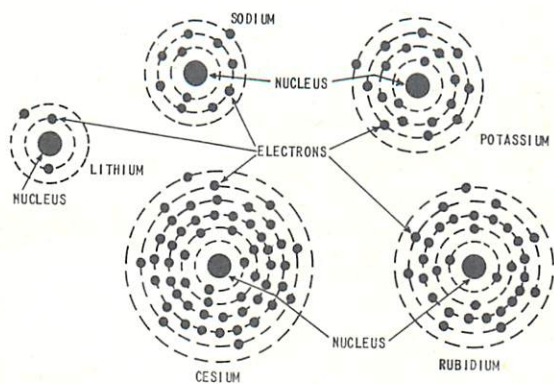


FIGURE 1

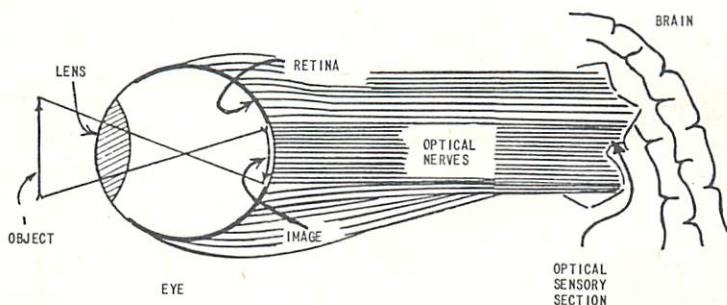


FIGURE 2

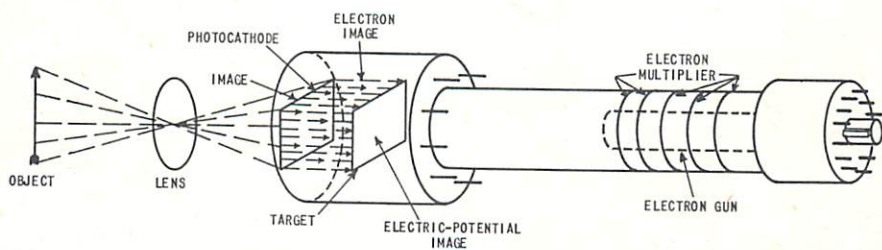


FIGURE 3

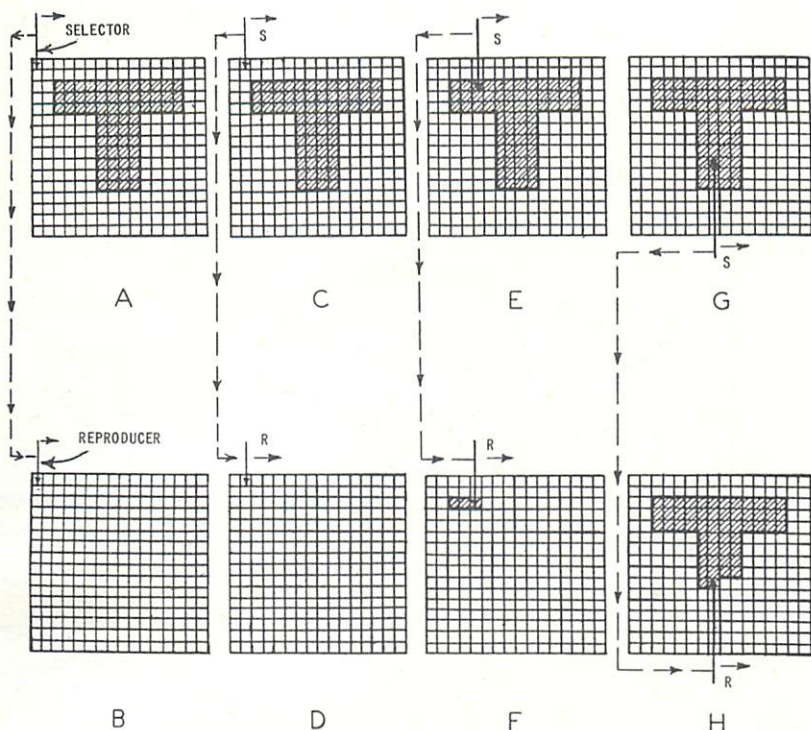


FIGURE 4

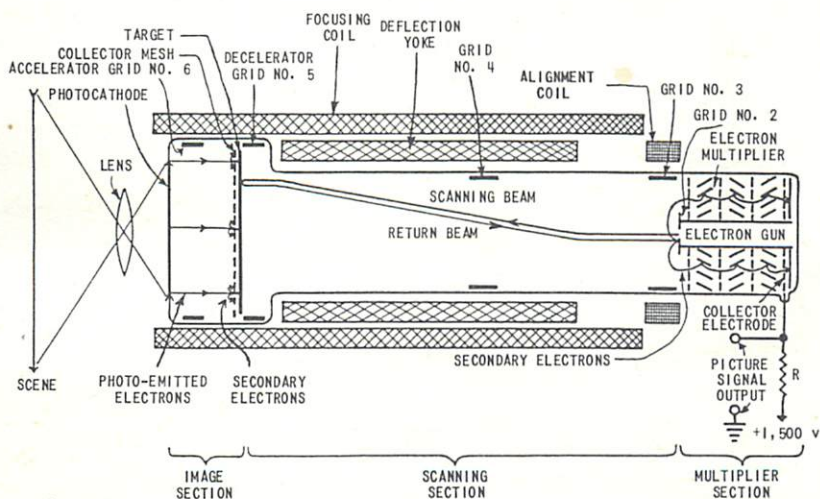


FIGURE 5

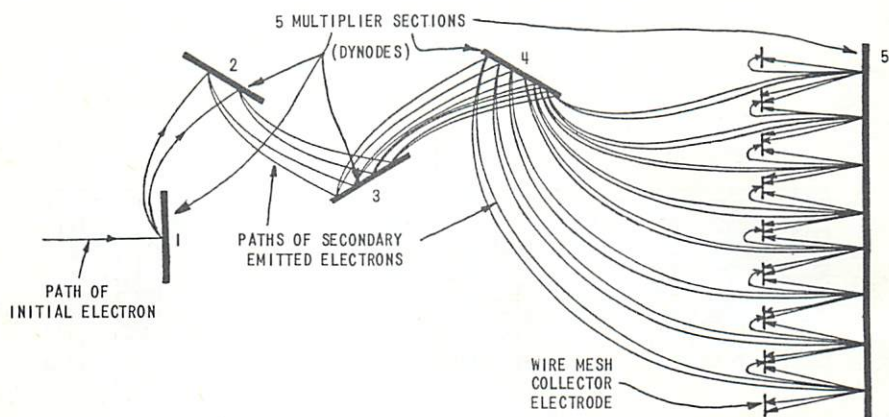
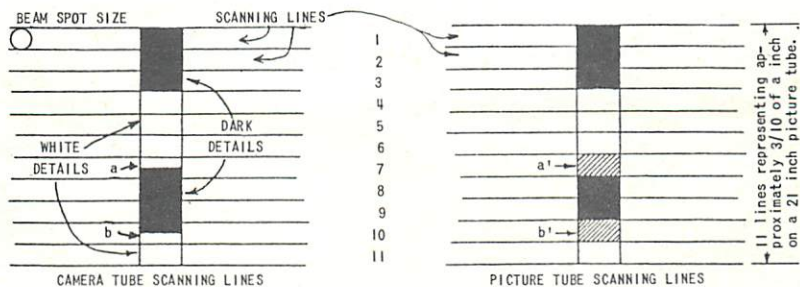
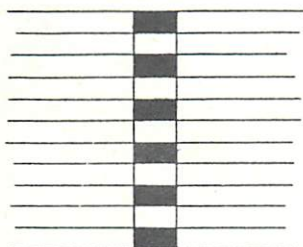


FIGURE 6

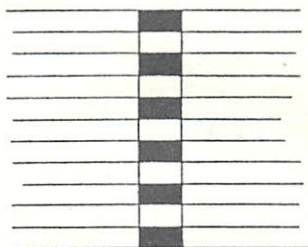


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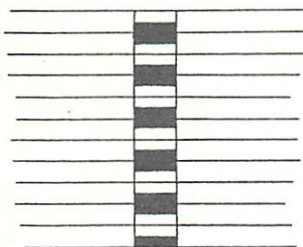
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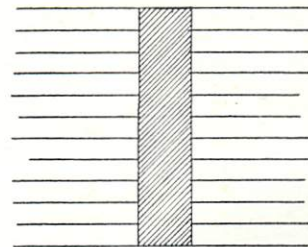
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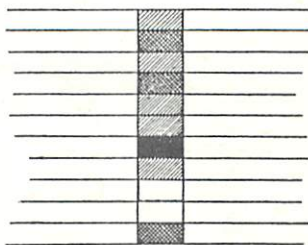


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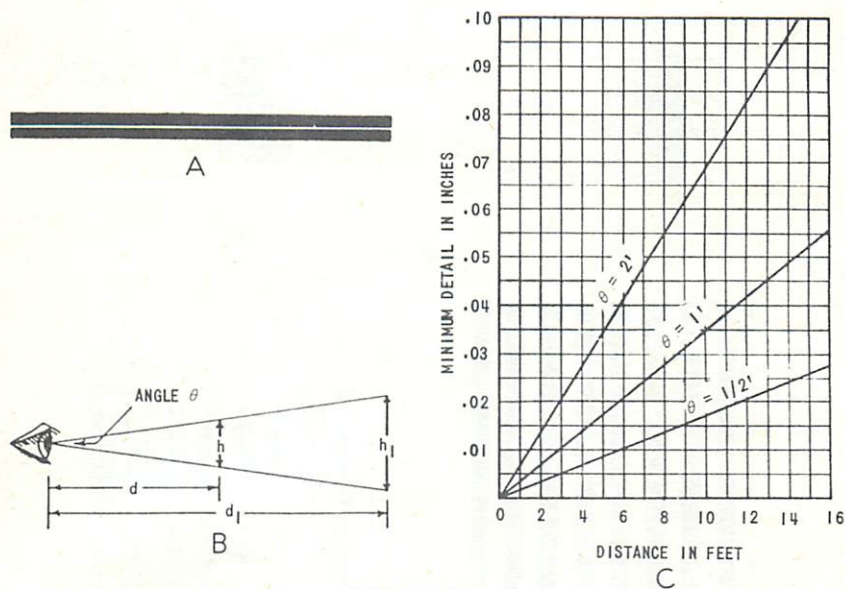


FIGURE 8

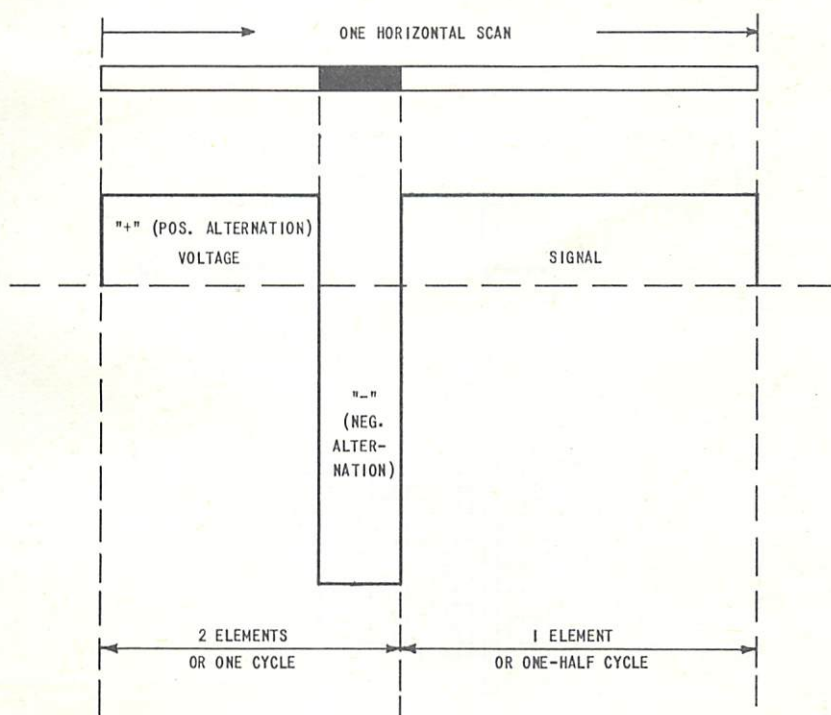


FIGURE 9

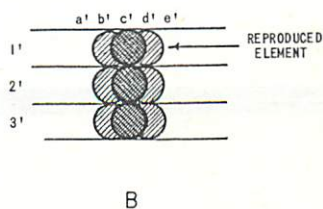
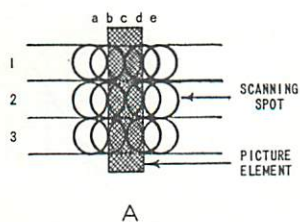


FIGURE 10

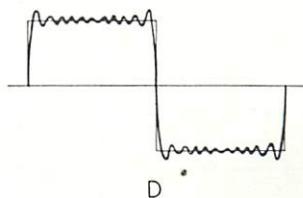
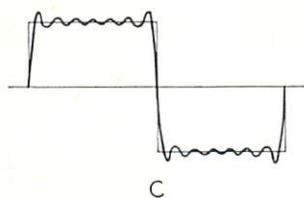
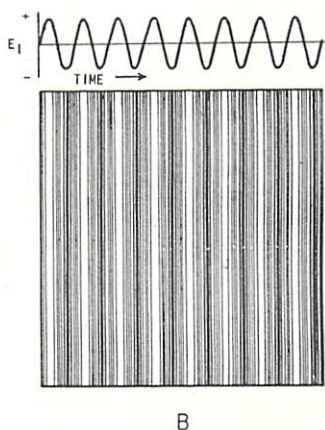
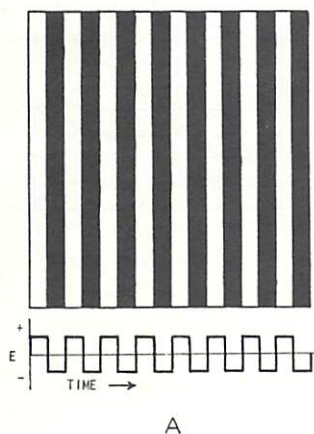


FIGURE 11

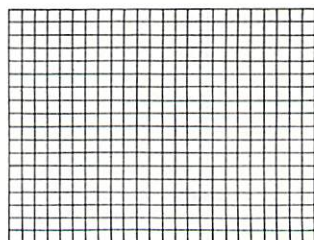


FIGURE 12

FROM OUR *Director's* NOTEBOOK

THE THIRD MAN

Every business, properly managed, takes an inventory of its stock and plant once a year.

Take an inventory of yourself.

Every man is, in a sense, three persons. One, the man he thinks he is; two, the man his friends think he is; three, the man he really is. The only one that you have to worry about is the third.

Study this Third Man. You can know him if you want. Write on a piece of paper the hours he works and the hours he wastes each day. Find out your true assets and liabilities.

Then you can deal with yourself on the basis of an honest trading account.

Yours for success,

W. C. Healy
DIRECTOR